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EXECUTIVE SUMMARY

This document presents the results of a groundwater characterization of a portion of the Santa Fe Springs oil field in Santa Fe Springs, California (**Figure 1**). The study was conducted on behalf of the Oil Field Reclamation Project (OFRP), a joint undertaking by the Community Development Commission of the City of Santa Fe Springs and the Mobil Oil Corp. The OFRP land consists of approximately 272 undeveloped acres (divided into 6 areas: Area A through Area F), much of which is expected to be developed over the next five to ten years (**Figure 2**).

The objectives of this groundwater characterization were:

- ▶ To characterize hydrogeologic conditions within the OFRP boundaries (depth to groundwater, type of groundwater bearing zone, physical characteristics, and the groundwater flow direction and gradient);
- ▶ To locate the major occurrences of chemicals in groundwater; and
- ▶ To identify if the likely sources of chemicals in the groundwater are within the OFRP boundaries.

SCOPE OF WORK

To achieve these objectives, a review of previous investigations conducted on OFRP land and a review of aerial photographs of the area was conducted to identify possible source areas that have potentially impacted groundwater. Twenty-seven groundwater monitor wells were installed downgradient and upgradient of the potential source areas identified from the records and aerial photograph review. During the installation of these wells soil samples were collected in the upper 15 feet and at other depths if soil contamination was observed. All these soil samples were analyzed for total recoverable petroleum hydrocarbons (TRPH) and selected

samples were analyzed for volatile organic compounds (VOCs). Following installation, three groundwater sampling events were conducted on a semi-annual basis (March 1994, October 1994 and April 1995). The groundwater samples were analyzed for total petroleum hydrocarbons (TPH), VOCs, semi-volatile organic compounds (SVOCs), metals, and general water quality parameters. Additional groundwater sampling was conducted on April 3, 1996 at three wells which were added to the OFRP study. The additional groundwater samples collected were analyzed for TPH, VOCs, SVOCs, and metals.

To determine the physical characteristics of the groundwater bearing zone, soil samples were collected from the groundwater bearing soil and analyzed for physical characteristics (hydraulic conductivity, effective porosity, average moisture content, dry and natural bulk density, and total organic carbon content). Slug tests were also conducted to determine the hydraulic conductivity of the groundwater water bearing zone at each OFRP well. A pumping test was conducted at MW-10 to determine the transmissivity of the groundwater bearing zone. These data was used to develop a groundwater flow model of the OFRP and surrounding area and to conduct contaminant (solute) transport modeling. The solute transport modeling was conducted to determine the possible future migration of any chemicals present in the groundwater and to help determine possible source areas that would produce the concentration and distribution of chemicals detected in groundwater.

RESULTS AND CONCLUSIONS

The groundwater characterization delineated the groundwater flow regime beneath the OFRP and revealed that a number of compounds and metals were present in groundwater at concentrations above regulatory limits and guidelines. Groundwater was encountered at an approximate average depth of 62 feet (ranging from 50.6 to 76.9 feet, April 1996) and is present in an unconfined aquifer consisting of Exposition and Gage aquifers which appear to be interfingered beneath the OFRP. Groundwater flow direction is to the southwest with an average gradient of 0.008 (42 ft/mile).

TPH is present in groundwater primarily in **Area C** of the OFRP. The TPH detected in groundwater primarily consisted of gasoline and diesel range hydrocarbons. VOCs were detected in all 27 groundwater monitor wells during at least one of the sampling events. Benzene, trichloroethene (TCE), and tetrachloroethene (PCE) were the most prevalent and

highest concentration compounds detected in groundwater. Benzene is present primarily in **Area B** and C of the OFRP. Elevated concentrations of toluene, ethylbenzene and xylenes are present within the area of the benzene plume. Elevated benzene was also detected in the southern portion of **Area F**. This benzene appears to be unrelated to the benzene found in Areas B and C. TCE and PCE plumes are present within the western half of **Areas A** and B. Elevated concentrations of 1,1-dichloroethene (1,1-DCE) are also present throughout this area. Lower concentrations of TCE and PCE have also been observed along the eastern boundary of OFRP **Areas E and F**.

The primary SVOCs detected in groundwater are phenolic compounds. Concentrations of phenolic compounds are present primarily in Area C along the boundary of Area E. A former phenol production facility was located in Area E, west of Old Romandel Avenue. Arsenic was detected in 12 of the 27 OFRP wells at concentrations above the maximum contaminant level (MCL). The highest concentrations of arsenic were measured in Areas B and C.

Soil samples were collected at each well location to determine if there was any impact to the near surface soils from former oil field operations. Soil samples were generally free of TRPH and VOCs. Of the soil samples which did contain detectable concentrations of TRPH, only one contained TRPH that exceeded 1000 parts per million (ppm).

A groundwater flow model was developed for the OFRP and surrounding area. Groundwater elevations were predicted by the model and calibrated to the groundwater elevations measured in the OFRP wells and five other wells located adjacent to the OFRP. The flow model was then utilized for solute (chemical) transport modeling. Based on the groundwater analytical results, benzene and TCE were selected to be modeled since they were the most prevalent compounds detected in groundwater. The predicted movement of the benzene and TCE plumes assumes that no additional contributions of these compounds will enter groundwater and that there are no continuous sources of these compounds present on- or off-site. With these assumptions the solute transport modeling indicates that benzene and TCE plumes currently present beneath areas A and B of the OFRP will migrate off-site over a period of 10 years, a portion of the benzene plume will still be present beneath the eastern section of Area B after 10 years, a lower concentration plume of TCE will still be present in the southern portion of Area F, and benzene will be present beneath the southern portion of Area F.

Potential source areas for benzene and TCE were simulated to determine if they would produce resultant chemical concentration distributions similar to those measured during the March 1994 sampling event. Based on the model, the sources of TCE are most likely to be from off-site locations and sources of benzene could be from both on-site and off-site locations.

Based on review of chemical data, groundwater flow conditions and the modeling results, the following conclusions were reached regarding probable sources of the primary chemicals observed beneath each area of the OFRP.

AREA A

Halogenated volatile organic compounds (HVOCs), primarily TCE, PCE, and 1,1-DCE, were detected at concentrations exceeding the MCL for drinking water within the western half of Area A. A soil investigation conducted in 1993 in the western half of Area A did not detect HVOCs in soil samples. Therefore, the data suggest that HVOCs are from an off-site upgradient source or sources.

TPH was not detected in Area A groundwater. Benzene and arsenic were detected in the eastern portion of Area A at concentrations slightly above their respective MCLs during the initial sampling event (March 1994) but were not detected in the subsequent 2 site wide sampling events.

Based on these data and data from Area B and Area C, it appears that TPH, benzene and arsenic are in groundwater beneath the southeast portion of Area A. These data suggest that these chemicals did not originate from Area A. Also there is no known source of arsenic in the OFRP.

Based on the results discussed above, chemicals found in groundwater beneath Area A have not originated within Area A.

AREA B

HVOCs, primarily TCE, PCE, and 1,1-DCE, were detected at concentrations exceeding the MCLs within the western half of Area B (west of Springdale Avenue). The distribution of these compounds indicate both off-site upgradient chemical sources and possible contributions within Area B west of Springdale Avenue. A soil investigation conducted in 1994 revealed that HVOCs were not detected in soil within former oil tank and sump areas and at grid sampling locations in the general areas of oil field operations. Therefore, the data show that HVOCs detected are not from prior oil field operations.

Vinyl chloride was detected at concentrations exceeding the MCL in the eastern portion of Area B during the initial monitoring event (March 1994). Vinyl chloride may be originating upgradient of Area B or from former activities conducted in the northeast portion of Area B, north of Park Avenue and east of Forest Avenue. Soil samples from a parcel known as the Beaumon Trust Property (located within the area north of Park Avenue and east of Forest Avenue), where drum rinsing occurred, shows a variety of HVOCs and BTEX in soil. The well with elevated vinyl chloride concentrations also contained PCE, cis-1,2-DCE, and 1,1-dichloroethane (1,1-DCA) above respective MCLs. These compounds are not seen directly upgradient. The detection limits for these compounds in the upgradient well were above the concentrations measured in the well adjacent to the Beaumon Trust Property due to high benzene concentrations.

Benzene was detected at concentrations exceeding the MCL in the eastern portion of Area B. The related compounds (toluene, ethylbenzene and xylenes) were also present with benzene. This chemical group is referred to as BTEX. TPH (primarily gasoline and diesel range hydrocarbons) was detected in groundwater in the northeast portion of Area B. The distribution of TPH, benzene and other BTEX compounds measured in the wells indicate benzene is migrating onto Area B from an upgradient source or sources. Sources of BTEX to groundwater have not been documented from oil field operations in Area B based on results from the 1994 soil investigation.

Concentrations of arsenic exceeding the MCL were detected in 6 of the 11 wells located in Area B during at least one of the two sampling events. There is no known source of arsenic in the OFRP.

Based on the results discussed above, chemicals found in groundwater beneath Area B have not originated from oil field operations. HVOCs and BTEX compounds may have originated from non-oil field activities west of Springdale Avenue and in the vicinity of Forest and Park Avenues.

AREA C

The only HVOC detected above its MCL was TCE. TCE was detected at or slightly above the MCL. Similar TCE concentrations were measured in wells on the upgradient and downgradient edges of Area C. TCE appears to originate upgradient of Area C.

Concentrations of benzene exceeding the MCL were detected. Concentrations of toluene, ethylbenzene, and xylene exceeding their respective MCLs were detected in one of the wells. Elevated concentrations of TPH (primarily diesel and gasoline range hydrocarbons) were detected in groundwater beneath Area C. The distribution of TPH, benzene and other BTEX compounds measured in the wells indicate benzene is migrating onto Area C and may also be originating from former activities within Area C. Groundwater data indicates that the primary source of the benzene measured in Area C and extending into Area B is from operations in Area E and/or sources further upgradient. Former operations in Area E, between Old Romandel Avenue and the railroad tracks, included storage of benzene in tanks. This property has been occupied by Golden Eagle Refinery, Productol, Inc. and PMC. A soil investigation conducted in Area C indicated that TPH (crude oil and refined hydrocarbons) and BTEX compounds were in soil. BTEX concentrations increased at depth at one of the boring locations in the southwest corner of Area C and does not appear to be representative of oil field operations. The impacted soil may be associated with other oil operations (pipelines). The source of this impact is currently being investigated by the property owner.

Elevated concentrations of phenolic compounds were detected in groundwater in monitor wells located along eastern boundary of Area C. The sources of these compounds are suspected to be from previous operations conducted in Area E, west of Old Romandel Avenue, and/or sources further upgradient. Former operations in Area E, west of Old Romandel Avenue, included the production and storage of phenolic compounds.

Concentrations of arsenic exceeding the MCL were detected in Area C. There is no known source of arsenic in the OFRP.

Based on the results discussed above, HVOC, phenolic compounds and arsenic found in groundwater beneath Area C have not originated from activities in Area C. Activities in the southwest corner of Area C may have contributed BTEX and TPH to groundwater.

AREA D

One well was installed at the southwest corner (downgradient corner) of Area D. Results from this well indicate that TCE and PCE and benzene have been detected slightly above their MCLs during at least one of the three sampling events. Arsenic was not detected; however, based on the concentrations of arsenic in wells located in Areas B and C it is probable that arsenic is in groundwater beneath the northwest portion of Area D. There is no known source of arsenic in the OFRP. A portion of the northern section of Area D was remediated as a result of TPH impacted soil.

Based on the results discussed above, chemicals found in groundwater beneath Area D have not originated in Area D.

AREA E

Two groundwater monitoring wells were installed along the upgradient boundary of Area E. Four groundwater monitoring wells were constructed and one grab sample of groundwater was collected during earlier studies unrelated to the OFRP. Monitoring results from these wells indicate TCE slightly above its MCL and appears to originate from upgradient, off-site sources.

Benzene tanks were present in the southern half of Area E west of Old Romandel Avenue. A grab groundwater sample collected adjacent to one of these benzene tanks during a 1988 site investigation contained high concentrations of benzene. There are no OFRP wells directly upgradient from the former benzene tanks in Area E to assess if there is contribution from any other upgradient sources.

Phenolic compounds detected in Area C wells are suspected to be from previous operations conducted in Area E west of Old Romandel Avenue. Former operations in Area E included the production and storage of phenolic compounds.

Based on the results discussed above, chemicals found in groundwater beneath Area E have not originated from activities in Area E east of Old Romandel Avenue and HVOCs have not originated from Area E. Monitoring results from wells located in Area C, across the railroad easement from Area E, indicate that the portion of Area E west of Old Romandel Avenue is a probable source of benzene and phenolic compounds detected in Area C wells.

AREA F

One well was installed at the southern tip of Area F. HVOCs were detected at concentrations exceeding the MCLs in this well and reflect an upgradient, off-site source or sources. Well installation was initially attempted in the southern portion of Area F in December 1993. The boring and well was not completed at this location as a result of high levels of soil vapors encountered during well drilling activities. A well was successfully installed adjacent to the previous location on March 11, 1996. A benzene concentration significantly above the MCL was detected in this well. This concentration originates from an upgradient off-site source, based on the groundwater gradient, information obtained from the Ashland Chemical Site located east of Area F and regulatory agency comments. The Ashland Chemical Site is a probable source of the benzene measured in Area F.

Barium was detected in the Area F well at a concentration above its MCL. This barium concentration appears to be originating from an upgradient source or sources from Area F. This is no known source of barium in Area F.

Based on the results discussed above, chemicals found in groundwater beneath Area F have not originated in Area F.

1.0 INTRODUCTION

McLaren/Hart Environmental Engineering Corporation (McLaren/Hart) conducted a groundwater characterization program for the Santa Fe Springs oil field in Santa Fe Springs, California. The study was conducted on behalf of the Oil Field Reclamation Project (OFRP), a joint undertaking of the Community Development Commission of the City of Santa Fe Springs, Mobil Oil Corporation, and Santa Fe Energy Resources. The OFRP Study Area consists of approximately 272 acres of undeveloped land, much of which is expected to be developed over the next five to ten years. **Figure 1** shows limits of the OFRP Study Area and the surrounding area.

1.1 SITE HISTORY AND DESCRIPTION

The City of Santa Fe Springs was originally founded as a retirement community for employees of the Santa Fe Railroad in the early 1900s. A train station was planned near Telegraph Road and the land closest to the train station was divided into individual lots for retired railroad employees (“Town Lots”). When oil was discovered near the Town Lots in the early 1900s, the area became an active oil field and the original development plans were abandoned.

Productivity of the oil field has declined in recent years, but the field continues to have economic potential. In the past 20 years, some industrial and commercial development has occurred on the periphery of the oil field. Most recently, three large parcels in the southeast corner of the oil field (outside the OFRP area) were developed by McGranahan, Carlson & Company. As part of the development, a comprehensive environmental investigation and soil cleanup was conducted under the guidance of the Regional Water Quality Control Board (RWQCB).

Figure 2 shows the six major areas within the OFRP, designated A through F. Area G consists of small parcels that lie to the west and south of the OFRP that may be included in the OFRP at some future time.

1.2 OBJECTIVES

The objectives of this groundwater characterization were:

- ▶ To characterize hydrogeologic conditions within the OFRP boundaries (depth to groundwater, type of groundwater-bearing zone, physical characteristics, and the groundwater flow direction and gradient);
- ▶ To locate the major occurrences of chemicals in groundwater; and
- ▶ To identify if the likely sources of chemicals in the groundwater are within the OFRP boundaries.

2.0 HYDROGEOLOGY

This section describes the regional geomorphology, structure, and hydrogeology, based on published data and from publicly available information in the files of the Los Angeles County Department of Public Works (LACDPW), State of California Department of Water Resources (CDWR) and the RWQCB.

2.1 REGIONAL GEOMORPHOLOGY AND STRUCTURE

The OFRP area is located approximately 150 feet above sea level. The geomorphology of the area is comprised of overlapping alluvial aprons with portions forming an undulating surface. The general slope direction is to the south to southwest. Numerous river and creek beds transect the area in a northeast to southwest trend. The “older” alluvial apron in the vicinity of the site is the Santa Fe Springs Plain. The Santa Fe Springs Plain appears to be an extension of the Coyote Hills uplift to the southwest (CDWR, 1990). The Santa Fe Springs Plain consists of a low slightly rolling topography which is probably due to warping caused by the northeast to southwest trending Santa Fe Springs-Coyote Hills anticlinal system. The Santa Fe Springs Plain dips gently to the northeast and southwest towards the “younger” La Habra Piedmont slope and Downey Plain, respectively.

The La Habra Piedmont slope consists of several small alluvial fans deposited by streams draining the Puente Hills. These series of small alluvial fans create a southeasterly trending topographic surface along the southwest foot of the Puente Hills (CDWR, 1990). The Downey Plain is the largest Recent alluvial deposition in the Los Angeles basin. This large topographical feature was formed by the coalescing of alluvial fans along the Los Angeles and San Gabriel River systems. The mergence of these large depositional features formed the gently sloping plain. The Downey Plain slopes to the southwest from 7 to generally less than 18 feet per mile.

In addition to the Santa Fe Springs-Coyote Hills anticlinal system, the other structural features in the area are the Norwalk syncline to the south, the Leffingwell anticline to the east, the La Habra syncline to the east and northeast, the Whittier fault zone to the northeast, and the numerous faults in the Whittier Narrows area to the north.

2.2 REGIONAL HYDROGEOLOGY

The Santa Fe Springs Plain is part of the Montebello Forebay non-pressure area of the Central Basin. Groundwater is found throughout the region under unconfined conditions in the Recent alluvium and in the underlying Exposition aquifer. Numerous other aquifers are also present in the area, and are under confined to semi-confined conditions: the Gage, Hollydale, Jefferson, Lynwood, Silverado, and Sunnyside aquifers (**Figure 3**). Within the OFRP, the upper 100 feet of sediments consist predominantly of very permeable sands, although the upper 15 feet of sediments have a higher silt and clay content and lower permeability.

According to geologic cross-sections presented in California Department of Water Resources (CDWR) Bulletin 104 (1990), there are two regional groundwater-bearing zones within the OFRP area: the first regional groundwater-bearing zone is the Exposition Aquifer, which is first encountered at approximately 60 feet below grade; the second regional aquifer is the Gage Aquifer, which is reported between 85 and 105 feet below grade (CDWR, 1990). Localized perched zones have been encountered as shallow as 13 feet below grade such as the shallow aquifer which has been reported along the railroad tracks in Area E (Kleinfelder, 1986).

Information from the LACDPW - Hydrologic Records section indicates that the depth to water at well number 1625-N (located at the intersection of Telegraph Road and the Southern Pacific Railroad tracks approximately one-half mile west of the OFRP) was 58 feet below grade on April 30, 1992. This depth corresponds to the top of the saturated portion of the Exposition Aquifer.

Although most of the aquifers in the area are separated by aquicludes, the Hollydale and Gage are hydraulically connected approximately 2,000 feet north of the intersection of Telegraph Road and Norwalk Boulevard. Approximately 7,200 feet north of the intersection of Telegraph Road and Norwalk Boulevard, the Hollydale, Jefferson, and Lynwood Aquifers are

also hydraulically connected. There are domestic and commercial water wells screened in the Lynwood and Silverado Aquifers throughout the city.

The most significant hydrologic feature in the area is the San Gabriel River, which flows approximately north-south along the western edge of the city. There are also two extensive water spreading grounds/percolation basins approximately 1 to 2.5 miles northwest of the city limits. These features will act as groundwater recharge, or “mounding” areas, thus inducing groundwater to flow away from them.

3.0 PREVIOUS SOIL AND GROUNDWATER INVESTIGATIONS

This section discusses the sources of information on chemicals in soil, a summary of the available data, and a preliminary identification of potential sources based on previous soil and groundwater investigations. The reports reviewed that described these previous investigations are included in Section 9 - References.

Phase I and II soil and limited groundwater investigations have been previously conducted in several portions of the OFRP by McLaren/Hart and other environmental consulting firms for property owners and operations of facilities located in the OFRP. Soil samples have been collected on approximately 185 of the 272 acres within the OFRP. These soil samples were primarily collected in Areas A, B and C. Thirteen groundwater monitor wells were constructed within or adjacent to the OFRP as part of some of these previous investigations.

All available data were compiled and reviewed and the most likely potential sources of groundwater contamination in each area were identified as part of the development of the Santa Fe Springs OFRP Groundwater Characterization Workplan. The information reviewed and summary of areas identified as potential sources of groundwater contamination are discussed in the following sections.

3.1 SOURCES OF INFORMATION

In developing the Workplan, the primary source of information on potential sources of chemicals in the OFRP groundwater was historic aerial photographs. The photographs used were shot in 1928, 1945, 1952, 1958, 1963, and 1978. Features visible on these photos that indicated potential chemical sources were identified and each feature was given a unique designation. The features from the aerial photographs that were noted were sumps, aboveground tanks, gas condensation plants, and dark areas potentially indicating surface spills.

The second source of information was the soil characterization reports that have been performed on eight areas within the OFRP. These data were collected by the individual landowners as part of earlier attempts to develop the sites or in response to agency requests for information. The third source of information was publicly available reports from regulatory agencies on known chemical discharges. Publicly available sources are referenced in this document. Information that was reviewed which was not publicly available is abstracted in the text of this document. Reports reviewed for investigations conducted by other consulting companies in other portions of the OFRP is listed in Section 9.0 References.

Data from all three sources data were evaluated and compiled. Information from aerial photos was digitized on to AutoCAD drawings to locate the potential chemical sources. The areas identified from these three information sources are shown on **Figure 4** (Figure 6 from Workplan). The areas identified on Figure 4 were limited to aboveground tanks and sumps. A gas condensation plant was identified in the western half of Area A east of T22A but is not shown on Figure 4.

3.2 SUMMARY OF CHEMICALS OF INTEREST

The OFRP area was subdivided into six areas labeled A through F. McLaren/Hart prepared a workplan “*Workplan to Characterize Groundwater at the Santa Fe Springs Oil Field*,” dated November 17, 1993, which discussed in detail the chemicals of interest and potential sources in the OFRP area. This section summarizes some of the information presented in the workplan and also includes additional information which was not available at the time the workplan was submitted.

The primary chemical of interest in this study is crude oil. Crude oil consists of a variety of organic compounds, which are collectively described as petroleum hydrocarbons. Petroleum hydrocarbons contain soluble and mobile volatile aromatic hydrocarbons such as benzene, toluene, xylenes, and ethylbenzene as well as larger and less mobile SVOCs, particularly polynuclear aromatic hydrocarbons (PAHs).

The major sources of crude oil in soil and groundwater at the OFRP are above ground tanks and sumps that were used during historic oil field development and operation. Lesser amounts

may be present from leaking pipelines, surface spills, or buried underground tanks, although these types of areas were not identified from the aerial photographs.

An investigation of Area B was performed by McLaren/Hart. Results of this investigation were presented in a report entitled "*Phase II Environmental Assessment of the Town Lots in Santa Fe Spring, California*" dated December 22, 1994. This report confirmed that the primary chemicals in soil resulting from oil field operations were TRPH and BTEX compounds.

An additional limited soil investigation of Area C was performed by McLaren/Hart. This investigation was conducted to provide vertical definition at locations identified from an 1988 soil investigation conducted by Applied Geosciences which indicated refined petroleum hydrocarbons at depth. Results of the June 1996 investigation indicate elevated concentrations of TPH and BTEX at depth at one boring location in the southwest corner of Area C. The BTEX concentrations were primarily detected at depth with the highest concentrations measured just above the water table. The concentrations of BTEX compounds detected in this boring indicate a refined petroleum hydrocarbon source possibly associated with former or current pipelines located in or adjacent to the southwest corner of Area C.

Locations within the OFRP are known to have chemicals in soil other than (or in addition to) petroleum hydrocarbons. These chemicals include phenolic chemicals, "wood treating chemicals" (creosote and pentachlorophenol), and chlorinated and aromatic volatile organic compounds. Creosote and pentachlorophenol was detected in soil in a subleased portion of Area A. This area was subleased by Ugalde, a construction company which is believed to have used wood treating chemicals as part of their construction yard operations.

Phenolic compounds and benzene were used and stored in Area E (PMC Specialties Property).

Chlorinated and aromatic organic compounds were detected in soil in parcel 15 (Beaumont Trust Property) located in the northeast section of Area B. Site investigation activities have been conducted at the Beaumont Trust Property under the direction of the Los Angeles County Fire Department.

Information regarding the Ashland Chemical Site is also referenced in this report. The Ashland Chemical site is located at 10505 South Painter Avenue approximately 1,400 feet east of Area F. Groundwater impact of aromatic and HVOCs have been documented at this site and it possibly has impacted a portion of the OFRP Study Area.

Benzene was stored in several tanks at the PMC Specialties site located in Area E. A groundwater grab sample (KB-1) collected adjacent to one of the benzene tanks during an investigation conducted by Kaman Tempo in 1988 contained a benzene concentration of 32,000 $\mu\text{g/l}$ (parts per billion, ppb). Ponding of benzene near 3 of the aboveground tanks had previously been observed by Ferro Corporation employees prior to PMC Specialties acquiring the property in 1986. Benzene was not analyzed in wells MW-1, MW-2 and MW-3 or detected in well MW-3 installed on the PMC property (refer to **Figure 35**).

Other environmental issues such as methane gas and asbestos were not addressed in this study because they do not directly impact groundwater.

3.3 SUMMARY OF POTENTIAL SOURCES

As part of the development of the workplan the available data were compiled and the areas with the greatest potential to be sources of chemicals to the groundwater were identified using the following criteria:

- ▶ **Documented Chemicals in Groundwater.** Chemical data from groundwater monitor wells is an important criterion for identifying a potential source. A site is identified as a potential source if groundwater data indicate that chemicals are present beneath the site or downgradient, but not detected upgradient, and chemicals detected in groundwater were used in source areas.
- ▶ **Depth of Chemicals.** The second important criterion that would indicate whether a site is a potential source of groundwater contamination is the depth at which chemical residues are observed in soil. Since the permeability of soil within the OFRP increases below 15 feet and groundwater is present as high as 54 feet below grade, a site is considered a potential source if chemicals are found at a depth of 20 feet or greater (i.e., into the more permeable sand).

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- ▶ **Time.** In the absence of chemical data, the most important criterion is the length of time that surface features such as aboveground tanks or oil sumps were in use. The longer these tanks or sumps were in use (i.e., the more times they were observed on historic aerial photographs), the more likely they are to have leaked.
 - ▶ **Surface Area.** The fourth criterion for ranking sites is surface area. For sites that have the same length of time in operation, those sites with the greater surface area are considered to be more likely to have been a source of chemicals to the groundwater.

This evaluation identified the twelve most likely sources of chemicals to the groundwater within the OFRP. Two of the sites have groundwater data showing chemicals in the groundwater. Three of the sites are included based on the depth of chemicals in the soil. Seven of the sites are included based on time of use and surface area observations from aerial photographs. These sites are identified on **Figure 4** and were described in the groundwater characterization workplan.

4.0 GROUNDWATER INVESTIGATION

4.1 GROUNDWATER MONITOR WELL CONSTRUCTION AND DEVELOPMENT

The groundwater investigation of the OFRP consisted of installing 27 groundwater monitor wells in the Exposition Aquifer (i.e., the saturated zone ranging from approximately 60 to 80 feet throughout the area). Twenty-three of these wells were installed in December 1993 through January of 1994 and three additional wells were installed in September 1994 after the data from the first 23 wells was evaluated. One well that was unable to be completed during the initial set of well installations was successfully installed in March 1996. Eleven of the first 23 wells were placed downgradient of the 12 sites identified in Section 3.3 of the “*Workplan to Characterize Groundwater at the Santa Fe Springs Oil Field*,” dated November 17, 1993, as potential source areas. The remaining 12 wells were placed throughout the OFRP to provide coverage of the entire area. **Figure 5** shows the locations of 27 groundwater monitor wells (MW-1 through MW-25).

The Workplan included the installation of a total of 30 groundwater monitor wells. Twenty-four were to be placed first followed by 6 additional wells based on data from the first 24. Twelve of the first 24 were to be placed downgradient of twelve potential source areas. However, during the installation of the well (MW-22) adjacent to the tank battery in Area F, high levels of VOCs were detected and high readings were measured on the field Lower Explosive Limit (LEL) meter. The high levels of VOCs and high LEL readings persisted during the drilling activities, therefore the well installation activities were terminated and the hole backfilled. Well MW-22 was successfully installed adjacent to its originally proposed location in March 1996. In addition, only three of the six additional wells were completed since the other three proposed well locations were within private properties and access was not granted by the property owners.

4.1.1 Well Construction Details

Protocols for well construction are included as Appendix A of this report. All groundwater monitor wells were installed to a depth of 15- to 40-feet below the surface of the first regional aquifer encountered. Four of the wells (one in each quadrant of the OFRP) were drilled to a depth of at least 120 feet to document geologic conditions below the water table. These wells were backgrouted and screened in the same depth interval as the other wells. A summary of the well construction details is presented in **Table 1**.

All wells were constructed using 4-inch PVC casing and slotted screen with a slot size of 0.020 inch. A typical well construction diagram for the OFRP is presented in Appendix A. Details of the well construction for each well is presented on the soil boring/well construction logs in Appendix B.

4.2 GROUNDWATER MONITOR WELL SURVEY AND WATER LEVEL SOUNDING

The 27 groundwater monitor wells were surveyed by a State of California Licensed Land Survey with respect to a known benchmark. All wells were surveyed with respect to lateral coordinates and elevation.

Five groundwater monitor wells (MMW-1 through MMW-5) installed by Mobil Oil Company and two groundwater monitor wells (MCC-2 and MCC-4) installed by McGranahan Carlson & Company located adjacent to the OFRP were also surveyed (Figures 6A & 6D). Data from these groundwater monitor wells was used as part of the OFRP study and is presented in this report.

Groundwater monitor wells utilized for the OFRP study were sounded on a semi-annual basis (March 1994, October 1994, and April 1995) to determine depth to groundwater in each well. The surveyed top of casing elevation was then used to calculate groundwater elevation at each well location.

An additional sounding was conducted in April 1996 to incorporate well MW-22 (installed March 1996) and the two McGranahan Carlson wells located in the vicinity of MW-22.

4.3 SOIL SAMPLING

Soil samples were collected during well installation, at depths of 5, 10, and 15 feet from each well boring. These samples were analyzed for TRPH by EPA Method 418.1. Soil samples collected from well MW-22 were analyzed for TPH by EPA Method 8015 as a result of the laboratory utilized for the study has discontinued the use of EPA Method 418.1 prior to the installation of MW-22. If the soil color, odor, or field instrument readings indicated possible chemicals below 15 feet, additional samples were collected and analyzed for VOCs by EPA Method 8240. Soil sampling protocols are included in Appendix A. The soil laboratory analytical data sheet are included in Appendix C.

Samples from the four wells drilled to at least 120 feet were also collected for physical parameters such as bulk density, total organic carbon content, moisture, porosity, permeability, and grain size distribution to provide site specific data for development of a groundwater model. Samples were collected from the different lithologies, below the groundwater interface, at each of the four wells. The soil physical parameter laboratory data sheets are included in Appendix D.

Since the 27 wells were located outside of suspected chemical source areas, it was not anticipated that the soil cuttings would require special disposal. However, pending analytical results from the three soil samples per boring, soil cuttings were segregated on plastic lining. If the results indicated that the soil did not require handling as a special waste, it was left on site.

4.4 GROUNDWATER SAMPLING

The groundwater monitor wells were sampled three times during the course of one year. The initial sampling was completed in March 1994 and semi-annual sampling events were completed in October 1994 and April 1995. Groundwater samples collected during the first sampling round were analyzed for TPH by EPA Method 8015M, VOCs by EPA Method 8240, SVOCs by EPA Method 8270, and California Assessment Manual (CAM) metals by EPA Method 6010/7000 series. Groundwater samples from four selected monitor wells were also analyzed for general minerals; ion balance; Langelier index; specific conductance by EPA Method 120.1; total suspended solids (TSS) by EPA Method 160.2; chemical oxygen demand

(COD) by EPA Method 410.4; and biological oxygen demand (BOD) by EPA Method 405.1. Groundwater samples collected during the second sampling round were analyzed for TPH, VOCs, and SVOCs. Groundwater samples collected during the third sampling round were analyzed for TPH, VOCs, phenols (EPA Method 8040), and CAM metals. Additional groundwater sampling for wells MW-22, MCC-2 and MCC-4 was conducted in April 1996. Groundwater samples from these wells were analyzed for TPH, VOCs, SVOCs and CAM metals.

Groundwater sampling protocols and the Quality Assurance/Quality Control (QA/QC) plan are included as Appendix A. The groundwater laboratory analytical data sheets are included in Appendix E.

5.0 INVESTIGATION RESULTS

5.1 SITE HYDROGEOLOGY

5.1.1 Lithology

Lithologic data obtained during the groundwater monitor well installation phase indicated the soils in the OFRP are homogeneous. The soils above, and within the first encountered water bearing aquifer are divided into two groups: the upper and lower soil zones.

The upper soil zone composition ranges from silt to fine sand with interbeds of medium to coarse sand. The upper soil zone ranges in thickness from 7.5 to 75 feet across the OFRP. The upper soil zone is thinnest in the southeastern portion of Area C and in Area D ranging from 7.5 to < 20 feet in thickness. The upper soil zone is thickest in the central portion of Area B ranging from 61 to 75 feet in thickness. The upper soil zone in the remainder of the OFRP has an average thickness of 33 feet.

The lower soil zone composition ranges from medium to very coarse sand with silt to fine sand interbeds. Occasional lens of gravel to gravelly sand were observed at depths greater than 75 feet below ground surface. Due to the homogeneity of this zone, the distinction between the Exposition and Gage Aquifers could not be determined. It appears that these two regional aquifers interfinger beneath the OFRP. The water bearing portions of both the upper and lower soil zones are unconfined. All lithologic data obtained during well installation is presented in the soil boring/well construction logs (Appendix B).

5.1.2 Groundwater Flow Direction and Gradient

Hydrologic data was obtained from the wells at the OFRP during four monitoring periods (March 1994, October 1994, April 1995, and April 1996). Monitoring data collected during

March, 1994 indicated the depth to groundwater ranged from 57.02 to 73.56 feet below ground surface. During the April 1996 monitoring event, the depth to groundwater ranged from 50.64 to 76.89 (76.89 feet measured in MW-22 had not been installed at the time of the March 1994 monitoring event). Groundwater levels have risen an average of 3.64 feet from March 1994 to April 1996 in the OFRP wells. The depth to groundwater was greatest in the north and shallower to the south. The groundwater flow direction in the northwestern portion of the OFRP area was to the southwest and in the southwestern portion of the OFRP area the flow direction was to the south during all sounding events (**Figure 6A** through **6D**). The groundwater flow gradient was calculated for March and October 1994, April 1995, and April 1996 sampling events are similar for all monitoring episodes. The calculated average groundwater flow gradient for all four monitoring episodes was 0.0080 and ranged from 0.0058 to 0.0135. The area with the steepest gradient was between monitor wells MW-12 and MW-13.

5.2 SOIL ANALYTICAL RESULTS

Soil samples were collected from 27 groundwater monitor well locations in the OFRP Areas A through F. The soil sample results from the 27 groundwater monitor well locations are described below.

5.2.1 Chemical Parameters

Soil samples were collected at approximately 5 foot intervals to a depth of 15 feet from 27 groundwater monitor well locations and analyzed for TRPH (TPH at MW-22). If field observations (odors, color, or field instruments) indicated the potential presence of other chemicals, samples were collected and analyzed for VOCs. A total of 83 soil samples were collected during the installation of the groundwater monitor wells. All samples were collected and analyzed for TRPH and two samples were collected and analyzed for VOCs (**Table 2**). Five additional soil samples were collected from soil cuttings stockpiled adjacent to each well and analyzed for VOCs.

The results of 73 of the samples analyzed for TRPH were below the reporting limit of 50 parts per million (ppm). The results of 8 of the samples (MW-5-5', MW-13-5', MW-23-5', MW-24-15', MW-29-5', 10', and 15', and MW-30-10') analyzed for TRPH were detected

above the reporting limit but below 1,000 ppm. The TRPH results of one sample (MW-24-5') was reported at 2,600 ppm. Two samples (MW-17-45' and MW-22-80-100') were analyzed for VOCs. The soil sampling results indicated a concentration of acetone at 100 parts per billion (ppb) in MW-17-45', and 57 ppb benzene and 42 ppb ethylbenzene in MW-22-80-100'. The soil sample collected from MW-22 for VOC analysis was collected from soil cuttings obtained from the saturated zone at a depth of 80-100 feet and therefore represents the influence of dissolved phase VOCs in groundwater.

In addition to the soil samples collected from the 27 groundwater monitor well locations, 5 of the soil stockpile areas (cuttings from well construction) were sampled and analyzed for VOCs. Except for the stockpile near MW-17, the results for VOCs were below the reporting limit for the stockpile soil samples. The results of soil sample from the stockpile pile near MW-17 detected acetone at 53 ppb.

5.2.2 Physical Parameters

Soil samples were collected at each change in lithology, below the groundwater interface, in four of the groundwater monitor wells (MW-5, -10, -17, and MW-23; one in each quadrant) and analyzed for the entire suite of physical parameters (hydraulic conductivity, effective porosity, average moisture content, dry and natural bulk density, and total organic carbon content). Additional soil samples were collected from monitor well borings MW-1, -3, -7, -14, -15, -21, and MW-24 and analyzed for effective porosity and average moisture content. The soil physical parameter results are presented in **Table 3**. The lithologic descriptions from the laboratory concur with the soil boring logs for each respective well. The results of the physical parameter analysis for the OFRP area indicate that the hydraulic conductivity ranges from 1.27×10^{-9} to 3.4×10^{-4} feet per second (ft/sec), the effective porosity ranges from 2.6 to 32.0 percent, the average moisture content ranges from 1.6 to 18.4 percent, the dry bulk density ranges from 1.40 to 1.75 grams per cubic centimeter (g/cm^3), the natural bulk density ranges from 1.88 to $2.11 \text{ g}/\text{cm}^3$, and the total organic carbon content ranges from 320 to 2,500 mg/kg.

5.3 GROUNDWATER ANALYTICAL RESULTS

Groundwater analytical results for the four monitoring events (March and October 1994 and April 1995 and April 1996) are presented in the following sections.

5.3.1 Total Petroleum Hydrocarbon Results

5.3.1.1 *March 1994*

During the initial groundwater sampling phase 10 of 23 wells contained detectable concentrations of TPH (**Table 4**). The detected concentrations of TPH ranged from 0.57 ppm to 22 ppm. The detected concentrations in the gasoline range ranged from 0.6 to 19 ppm. The detected concentrations in the kerosene range ranged from 0.57 to 16 ppm. The detected concentration in the diesel range was 4 ppm. The distribution of TPH concentrations in groundwater During March 1994 is shown on **Figure 7A**.

5.3.1.2 *October 1994*

During the second groundwater sampling phase 11 of 26 wells contained detectable concentrations of TPH (**Table 4**). The detected concentrations of TPH ranged from 0.5 ppm to 51 ppm. The detected concentrations in the gasoline range ranged from 2.1 to 28 ppm. The detected concentrations in the diesel range ranged from 0.78 to 51 ppm. The detected concentrations in the motor oil range ranged from 0.5 to 1.3 ppm. The distribution of TPH concentrations in groundwater during October 1994 is shown on **Figure 7B**.

5.3.1.3 *April 1995*

During the third groundwater sampling phase 11 of 26 wells contained detectable concentrations of TPH (**Table 4**). The detected concentrations of TPH ranged from 0.57 to 110 ppm. The detected concentrations in the gasoline range ranged from 0.37 to 4.7 ppm. The detected concentrations in the diesel range ranged from 0.31 to 110 ppm. The detected concentrations in the motor oil range were 0.57 and 0.6 ppm. The distribution of TPH concentrations in groundwater during April 1995 is shown on **Figure 7C**. TPH was not detected at MW-16 during April 1995 but was included within the 1 ppm contour interval

providing a contour map consistent with the adjacent wells and with the concentration distribution observed during the March and October 1994 sampling events.

5.3.1.4 April 1996

Groundwater sampling conducted in April 1996 was limited to the recently installed well MW-22 and McGranahan Carlson Wells MCC-2 and MCC-4. The groundwater samples collected from these wells contained detectable concentrations of TPH (**Table 4**). The detected concentrations of TPH ranged from 1.1 to 3.8 ppm. Gasoline range hydrocarbons were not detected in the samples. The detected concentrations in the diesel range were 2.8 and 1.1 ppm for MCC-2 and MCC-4, respectively. TPH detected in the sample collected from MW-22 entirely consists of kerosene range hydrocarbons. MCC-2 contained a concentration in the motor oil range of 0.82 ppm.

5.3.2 Volatile Organic Compound Results

5.3.2.1 March 1994

During the initial groundwater sampling phase, all 23 wells contained detectable concentrations of VOCs (**Table 5**). Benzene was detected above the MCL in 12 of the wells. Toluene, ethylbenzene, and xylenes were detected above their MCL in 2 of the wells. Tetrachloroethene (PCE) was detected above its MCL in 14 of the wells. Trichloroethene (TCE) was detected above its MCL in 10 of the wells. 1,1-DCE was detected above its MCL in 7 of the wells. 1,1-Dichloroethane (DCA) was detected above its MCL in 5 of the wells. Cis-1,2-DCE was detected above its MCL in 5 of the wells. 1,1,1-Trichloroethane (TCA) was detected above its MCL in 4 of the wells. Vinyl chloride was detected above its MCL in 2 of the wells. Methylene chloride was detected above the California action level for drinking water (AL) in 2 of the wells. Groundwater monitor wells MW-4, MW-5, MW-6, MW-10, MW-12, and MW-13 contain the highest detected VOC concentrations in the OFRP study area during the March 1994 sampling event. Benzene, TCE and PCE appear to be the most prevalent and highest concentration VOCs detected in groundwater. Chemical concentration contours for these chemicals are presented on Figures 8, 9 and 10, respectively. Toluene, ethylbenzene and xylene were detected within the area of the benzene plume shown on Figure 8. 1,1-DCE was present within the area of the TCE and PCE plumes (Figures 9 and

10). These trends in chemical distribution were the same during the October 1994 and April 1995 sampling periods. The minimum contour interval (5 ppb) reflects the MCL for TCE and PCE in Figures 9 and 10. A minimum contour interval of 5 ppb was used for benzene (**Figure 8**) because the laboratory reporting limit (5 ppb) was greater than the MCL for benzene which is 1 ppb.

5.3.2.2 October 1994

During the second groundwater sampling phase, 21 of 26 wells contained detectable concentrations of VOCs (**Table 5**). Benzene was detected above the MCL in 6 of the wells. Toluene, ethylbenzene, and xylenes were detected above the MCL in 2 of the wells. TCE was detected above the MCL in 12 of the wells. PCE was detected above the MCL in 10 of the wells. 1,1-DCE was detected above the MCL in 9 of the wells. 1,1-DCA was detected above the MCL in 2 of the wells. Cis-1,2-DCE was detected above the MCL in 2 of the wells. Vinyl chloride was detected above the MCL in 1 of the wells. Groundwater monitor wells MW-4, MW-5, MW-6, MW-10, MW-12, MW-13, MW-15, MW-17, MW-25, MW-29, and MW-30 contain the highest detected VOC concentrations in the OFRP study area during the October 1994 sampling event. Chemical concentrations contours for benzene, TCE and PCE are presented on Figures 11, 12 and 13, respectively.

5.3.2.3 April 1995

During the third groundwater sampling phase, 24 of 26 wells contained detectable concentrations of VOCs (**Table 5**). Benzene was detected above the MCL in 12 of the wells. Toluene, ethylbenzene, and xylenes were detected above the MCL in 2 of the wells. TCE was detected above the MCL in 14 of the wells. PCE was detected above the MCL in 11 of the wells. 1,1-DCE was detected above the MCL in 8 of the wells. 1,1-DCA was detected above the MCL in 4 of the wells. Cis-1,2-DCE was detected above the MCL in 4 of the wells. Vinyl chloride was detected above the MCL in 1 of the wells. Methylene chloride was detected above the AL in 1 of the wells. Groundwater monitor wells MW-4, MW-5, MW-6, MW-10, MW-12, MW-17, MW-25, MW-29, and MW-30 contain the highest detected VOC concentrations in the OFRP study area during the April 1995 sampling event. Chemical concentrations contours for benzene, TCE and PCE are presented on Figures 14, 15 and 16, respectively.

5.3.2.4 April 1996

Groundwater sampling conducted in April 1996 was limited to the recently installed well MW-22 and McGranahan Carlson Wells MCC-2 and MCC-4. VOCs were detected in all three wells (**Table 5**). Benzene was detected above the MCL in all three wells with the highest concentration of 5,800 ppb detected in MW-22. Toluene was detected above the California Action level in wells MCC-2 and MCC-4. Ethylbenzene were detected in all three wells but at concentrations below the MCL. Xylenes were detected in MCC-2 and MCC-4 at concentrations below the MCL. PCE was detected above the MCL in MCC-2 and MCC-4. 1,1-DCA was detected above the MCL in MCC-2. As a result of the high concentration of benzene detected in MW-22 the detection limit for the remaining VOC analytes tested were higher than the concentrations measured in MCC-2. Chemical concentrations contours for benzene, TCE and PCE are presented on Figures 17, 15 and 18, respectively. These figures include the April 1995 data to provide a comparison of the limited April 1996 sample data with the most recent site wide sample data.

5.3.3 Semi-Volatile Organic Compound Results

5.3.3.1 March 1994

During the initial groundwater sampling phase, 22 of 23 wells contained detectable concentrations of SVOCs (**Table 6**). 2,4-Dimethylphenol was detected above the AL in 2 of the wells. Bis(2-ethylhexyl)phthalate was detected above the MCL in 2 of the wells. Phenol was detected above the AL in 1 of the wells. Other SVOCs detected, but do not have established MCLs or ALs, include other phenol, phthalate, and naphthalene compounds. Groundwater monitor wells MW-12 and MW-16 contain the highest detected SVOC concentrations in the OFRP study area during the March 1994 sampling event.

5.3.3.2 October 1994

During the second groundwater sampling phase, 21 of 26 wells contained detectable concentrations of SVOCs (**Table 6**). Phenol was detected above the AL in 4 of the wells. 2,4-Dimethylphenol was detected above the AL in 3 of the wells. Bis(2-ethylhexyl) phthalate

was detected above the MCL in 11 of the wells. Other SVOCs detected, but do not have established MCLs, include other phenol, phthalate, and naphthalene compounds. Groundwater monitor wells MW-15, MW-16, and MW-17 contain the highest detected SVOC concentrations in the OFRP study area during the October 1994 sampling event.

5.3.3.3 April 1995

During the April 1995 groundwater sampling event groundwater samples were analyzed for phenols only. Seven of 26 wells contained detectable concentrations of phenolic compounds (**Table 6**). Phenol was detected above the AL in 2 of the wells. 2,4-Dimethylphenol was detected above the AL in 2 of the wells. The other phenolic compounds detected do not have established MCLs or ALs. Groundwater monitor wells MW-16, and MW-17 contain the highest detected phenolic compound concentrations in the OFRP study area during the April 1995 sampling event.

5.3.3.4 April 1996

Groundwater sampling conducted in April 1996 was limited to the recently installed well MW-22 and McGranahan Carlson Wells MCC-2 and MCC-4. MW-22 and MCC-2 contained detectable concentrations of SVOCs (**Table 6**). Naphthalene and 2-methylnaphthalene was detected in MW-22 and MCC-2. Bis(2-ethylhexyl) phthalate was detected above the MCL in MCC-2. Dimethylphthalate was also detected in MCC-2. Phenolic compounds were not detected in MW-22, MCC-2 and MCC-4.

5.3.4 California Assessment Manual (Title 22) Metals

5.3.4.1 March 1994

During the initial groundwater sampling phase, all 23 wells contained one or more of the California Assessment Manual (Title 22) Metals (**Table 7**). Many of the metals concentrations detected in groundwater are consistent with normal background levels. Metals are not discussed herein except where MCLs or other regulatory indicators are exceeded.

Arsenic was detected above the MCL in 11 of the wells. Selenium was detected above the MCL in 2 of the wells. Chromium was detected above the MCL in 1 of the wells. Arsenic is the most prevalent and highest concentration VOCs detected in groundwater. Arsenic concentrations contours are presented on **Figure 19**. The minimum contour interval shown on Figure 19 reflects the MCL for arsenic (50 ppb).

MCLs are not established for copper, nickel, vanadium, and zinc.

5.3.4.2 *October 1994*

The groundwater samples were not analyzed for metals during the October 1994 sampling event.

5.3.4.3 *April 1995*

During the third groundwater sampling phase, all 26 wells contained one or more of the California Assessment Manual (Title 22) Metals (**Table 7**). Arsenic was detected above the MCL in 11 of the wells. Selenium was detected above the MCL in 1 of the wells. Chromium was detected above the MCL in 1 of the wells. Arsenic concentrations contours for April 1995 are presented on **Figure 20**. Other detected metal concentrations measured in groundwater were consistent with normal background levels.

5.3.4.4 *April 1996*

Groundwater sampling conducted in April 1996 was limited to the recently installed well MW-22 and McGranahan Carlson Wells MCC-2 and MCC-4. During the April 1996 groundwater sampling, all 3 wells contained one or more of the California Assessment Manual (Title 22) Metals (**Table 7**). Arsenic was detected slightly above the MCL in MCC-2. Barium and chromium was detected above the MCL in MW-22. Other detected metal concentrations measured in groundwater were consistent with normal background levels with the exception of barium which was measured above normal background levels in MCC-2 and MCC-4, but were at concentrations below its MCL. The arsenic results for wells MW-22, MCC-2 and MCC-4 are presented on **Figure 20**.

5.3.5 General Minerals

Four of the wells (MW-5, MW-10, MW-17, and MW-23), one from each quadrant, were analyzed for general chemistry (**Tables 8a** and **8b**). Total dissolved solids (TDS), specific conductance, chloride, nitrate and sulfate are the only parameters with established MCLs. Specific conductance and TDS were detected above the MCL in all four wells. Chloride was detected above the MCL in 2 of the wells and sulfate was detected above the MCL in the other two wells.

6.0 AQUIFER TESTING AND RESULTS

Aquifer tests were conducted to determine hydrogeologic parameters necessary to characterize the groundwater bearing zone and to be used in the groundwater flow and chemical transport model developed for the site. The aquifer tests consisted of slug tests conducted in the original 23 OFRP groundwater monitor wells and a pump test conducted in the center of the study area.

An electronic, automated data logger and pressure transducers were used to measure water levels through time during recharge and recovery phases of the aquifer tests (slug and pump tests). For the pump test, transducers were placed in the pumped well (MW-10) and the three closest observation wells (AMW-1, AMW-5, and AMW-7). In addition, two OFRP wells MW-12 and MW-9 located closest to MW-10 were monitored periodically using a water level sounder. All aquifer test data was analyzed using “Aquifer Test Solver” ([AQTESOLV] Duffield and Rumbaugh, 1991), an interactive software program for analyzing slug and pumping test data collected from field aquifer tests.

6.1 SLUG TEST

Upon completion of the initial sampling episode of the 23 groundwater monitor wells, slug tests were performed in each well to calculate the hydraulic conductivity (K). Results of the slug tests were then analyzed using the computer program AQTESOLV which provides a graphical output of the results and calculates the hydraulic conductivity. Slug test protocols are included in Appendix A.

The average hydraulic conductivity calculated for the combined falling head and rising head tests at each well ranged from 2.43×10^{-3} ft/min to 6.74×10^{-2} ft/min with an overall average hydraulic conductivity of 1.63×10^{-2} ft/min . The slug test results are summarized in **Table 7**. These values for hydraulic conductivity are in the range of literature values of hydraulic

conductivity for fine sand and well sorted sands (Fetter, 1988). The distribution of K values indicate that the saturated zone is moderately heterogeneous across the site. Graphical output of the slug tests are included in Appendix F.

6.2 PUMPING TEST

After the slug tests were completed a step drawdown test was conducted in MW-10 (near the center of the OFRP study area) to determine the appropriate pumping rate for the constant rate 24-hour pumping test. The well was pumped at 8, 7.5, 6, and 6.5 gallons per minute (gpm) rates for 84, 70, 52, and 114 minutes, respectively. Based on the results of the test, 5.5 gpm was determined to be the appropriate rate for the continuous 24-hour test.

After the step drawdown test was completed, the well was given enough time to fully recharge and the 24-hour aquifer pumping test was conducted to determine the transmissivity of the groundwater bearing zone. The pump test utilized four groundwater monitor wells, OFRP well MW-10 and three wells on the Beaumont Trust property. Based on the results of the step drawdown tests, a pump rate of 5.5 gpm was used for the 24-hour test. The pump remained on for 731 minutes at which time the pump was turned off and the recharge recorded. Pumping test protocols are included in Appendix A.

A change in water level was observed in wells AMW-2, AMW-3 and MW-10 (the pumping well). Drawdown in the wells were 0.236, 0.285, and 9.882 feet, respectively. The water level in MW-10 approached steady-state equilibrium conditions, but was not fully reached by the end of the 12 hours when the well was pumped “dry”. Steady-state equilibrium conditions were not reached in the observation wells; however, the rate of water level change measured in the observation wells began to reduce (flatten out) by the end of the test. A sufficient level of equilibrium was reached in the pumped well and observation wells to determine transmissivity of the groundwater bearing zone.

AQTESOLV was used to estimate the transmissivity (T) using the Theis method and Cooper-Jacob method. The transmissivities calculated at the pumped well and from the adjacent observation wells are summarized in **Table 8**. The transmissivities are similar between both evaluation methods and between the two observation wells. The average transmissivity determined from the observation well data is 0.8678 and 1.149 ft²/min for the Theis and

Cooper-Jacob methods, respectively. Graphical output of the pumping tests are included in Appendix F.

7.0 GROUNDWATER SOLUTE TRANSPORT MODELING

This section presents the solute transport modeling approach using MODFLOW and MT3D computer codes. The objective of the modeling was to establish a simulated flow regime under natural flow conditions beneath the OFRP and surrounding area. Once the groundwater model simulating the natural flow conditions of the area was established a chemical transport model was developed to predict the movement of selected existing chemical plumes. Chemical transport modeling was also used to assist in determining possible sources of the chemicals by using the current distribution of chemical concentrations in groundwater and simulating sources that could develop into the current chemical plumes.

7.1 MODFLOW AND MT3D CODES

The computer simulations of groundwater flow and transport of selected chemicals were completed using MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1992), respectively. MODFLOW is the code that was used to simulate groundwater flow conditions over the modeled area. MODFLOW is a well documented 3-dimensional block-centered finite difference computer code developed by the United States Geological Survey. This code has a modular structure. The modules of the code are independent subroutines which deal with the specific features of the hydrologic system and can be used to simulate both unconfined and confined flow systems.

MT3D is a modular 3-dimensional transport model for simulation of advection, dispersion and chemical reactions of dissolved constituents in groundwater systems. MT3D uses a modular structure similar to that implemented in MODFLOW. The MT3D transport model is intended to be used in conjunction with any block-centered finite-difference flow model such as MODFLOW. MT3D retrieves the hydraulic heads saved from the flow model, automatically incorporating the specified hydraulic boundary conditions.

The MT3D transport model uses a mixed Eulerian-Lagrangian approach to the solution of the 3-dimensional advective-dispersive-reactive equation, in three basic options: the method of characteristics (MOC), the modified method of characteristics (MMOC), and a hybrid of these two methods (HMOC). The HMOC approach was selected for the OFRP model to provide minimalization of numerical dispersion of the transport solution while providing computational efficiency. Both MODFLOW and MT3D were run using *ModIME*. *ModIME* is a graphic pre- and post-processor developed by S.S. Popadopoulos & Associates, that links MODFLOW to MT3D.

7.2 MODEL INPUT PARAMETERS

Table 11 provides a summary of the hydrogeologic and geochemical input parameters for the MODFLOW and MT3D simulation. The input parameters for the model simulations were based on both field-measured parameters, including effective porosity, hydraulic conductivity, bulk density, saturated thickness, total organic carbon content, benzene and TCE concentrations, and hydraulic gradient, and conservatively estimated parameters, including aerial recharge and dispersion parameters based on published studies. The initial on-site plumes for benzene and TCE were conservatively modeled using the concentrations measured in the on-site wells during the March 1994 sampling event. Benzene and TCE plumes were selected to be modeled because these were the highest concentration and most prevalent compounds detected in the OFRP and selected Mobil wells. The TCE plume encompasses the other halogenated VOCs (PCE, 1,1-DCA, and 1,1- and cis-1,2-DCE) detected in groundwater.

The numerical flow model constructed using MODFLOW contained 1184 active cells in a single layer, 32 columns, and 37 rows. A variable grid spacing ranging from 200 to 1000-foot grid spacing was used for the flow domain for the simulation (**Figure 19**). Because it was impractical to extend model boundaries to the natural geologic boundaries of the system due to the large distances to potential barrier boundaries and surface water bodies, mathematical boundary conditions were used to simulate regional groundwater flow patterns. Regional flow was incorporated into the model using constant head nodes along the boundaries of the flow domain.

7.2.1 Hydrogeologic Parameters

The hydrogeologic input parameters were selected on the basis of data quality and/or conservativeness. The effective porosity (n_e) was set at 0.25, the value measured in the saturated zone soil samples from nine on-site wells and three Mobil wells located adjacent to the OFRP, which ranged from 0.026 to 0.32. Hydraulic conductivities were determined from slug tests conducted in wells MW-1 through MW-21, MW-23 and MW-24. Hydraulic conductivity zones were established based on the hydraulic conductivity values determined from the wells. The hydraulic conductivities used in the model range from 3 to 60 ft/day and are shown on **Figure 22**. The starting groundwater elevations used in the model were the groundwater elevations measured during the March 1994 sampling episode. The groundwater contours generated within the OFRP were extrapolated to the boundaries of the grid area (**Figure 23**). The aquifer thickness was set at 100 feet over the entire model area. Because the screened aquifer beneath the OFRP is unconfined the aquifer thickness was the depth from ground surface to the base of the unconfined aquifer which was approximately 100 feet across the OFRP.

7.2.2 Dispersivity

The process of hydrodynamic dispersion, including both pore-scale microdispersion and bed-scale macrodispersion, results in some contaminants arriving at downgradient well locations more rapidly than would be expected under advective flow only, a decrease of solute concentration with increased distance from the source, and greater lateral spreading in the direction of flow (longitudinal dispersion) than perpendicular to flow (transverse dispersion). Previous field investigations of dispersion have suggested that longitudinal dispersivity (α_L) varies as a function of the scale of the field problem with higher dispersivity values associated with greater transport distances and/or longer travel times (Pickens and Grisak, 1981; Gelhar et al., 1985). The longitudinal dispersivity was set at the low value of 10.00 to maintain a conservative approach. The lower the longitudinal dispersivity, the higher the predicted concentration for a given solute transport simulation.

The transverse dispersivity (α_T) for the site was assumed to be 1/10th α_L , which is consistent with previously reported values (e.g., Freeze and Cherry, 1979: $\alpha_T = 0.05-0.2 [\alpha_L]$; Freyberg, 1986: $\alpha_T = 0.10 [\alpha_L]$; Fetter, 1988: $\alpha_T = 0.25-0.50 [\alpha_L]$; Summers et al., 1989: $\alpha_T = 0.2-0.33 [\alpha_L]$). The vertical transverse dispersivity (α_{vT}) for the site was assumed to be 1/100th α_L , which is a conservative approach indicating that dispersion would preferentially occur in the horizontal direction.

7.2.3 Chemical Reaction

Retardation results from sorption of hydrophobic substances such as dissolved phase benzene onto soil particles, chemical interactions between subsurface fluids in primary and secondary pores and the geologic media, and migration into “dead-end” pores by diffusion (Leap, 1992). To account for the slower movement of dissolved benzene in the aquifer, a retardation factor (R_d) was determined using the following equation (Bouwer, 1991) and input parameters:

$$R_d = 1 + K_d (\rho_B / n_e)$$

and

$$K_d = F_{oc} K_{oc}$$

where:

- R_d = retardation factor for benzene: 1.83
- R_d = retardation factor for benzene: 2.30
- K_d = soil-water partition coefficient for benzene: $0.1028 \text{ cm}^3/\text{g}$
- K_d = soil-water partition coefficient for TCE: $0.1611 \text{ cm}^3/\text{g}$
- F_{oc} = average fraction organic carbon of aquifer sediment: 0.00106 g/g
- K_{oc} = organic carbon-water part. coef. for benzene: $97 \text{ cm}^3/\text{g}$ (Fetter, 1988)
- K_{oc} = organic carbon-water part. coef. for TCE: $152 \text{ cm}^3/\text{g}$ (Fetter, 1988)
- n_e = average effective porosity: 0.25
- ρ_B = average bulk density of aquifer sediment: 2.01 g/cm^3 .

The R_d of 1.83 means that the benzene moves approximately 85 percent slower than the groundwater in which it is being transported. The R_d of 2.30 means that the TCE moves over twice as slow as the groundwater in which it is being transported.

7.3 FLOW AND SOLUTE TRANSPORT MODELING RESULTS

7.3.1 Flow Model

The flow model was constructed and run prior to conducting the solute transport modeling. The purpose of the flow model was to simulate the groundwater elevation measured in the wells during the March 1994 monitoring event. The model was run to simulate natural flow conditions (steady-state simulation) for a simulated time period of one year. The flow model was calibrated by comparing the differences between model-predicted groundwater elevation (head) values and the head values measured from the March 1994 monitoring event.

A summary of the calibrated head differences is presented in **Table 12**. The greatest positive difference and greatest negative difference were 1.9 and -2.8 feet, respectively. The average difference in head was 0.77 feet. The greatest positive difference (1.9 feet) occurred at MW-12 and the greatest negative difference (-2.8) occurred at MMW-1. Calibration was achieved following completing a sensitivity analysis of the model.

The sensitivity analysis consisted of varying selected input parameters, within a range of values that were still consistent with field measurements or published information, to see which parameters had the greatest impact on the modeled head results. The recharge value, vertical and horizontal hydraulic conductivity values were varied as part of the sensitivity analysis. Based on head results the model was the most sensitive to horizontal hydraulic conductivity. Horizontal hydraulic conductivity was then varied until the lowest average difference between the modeled and measured heads was achieved.

7.3.2 Solute Transport Model

The purpose of conducting solute transport modeling was two fold: (1) to predict migration of the existing chemical concentrations over time; (2) to assist in determining possible sources of the chemicals. Benzene and TCE were the two chemicals modeled since these were the most

prevalent and highest concentration chemicals detected in groundwater. The migration of these compounds was modeled for a period of ten years. Several assumptions have been made in the solute transport model. Since the upgradient extent of TCE is not defined the modeled plume for TCE was assumed to be centered around MW-5 in Area B and MW-21 in Area F (**Figure 28**). The benzene and TCE plumes were modeled as discrete chemical plumes with no additional contributions of benzene or TCE being input into the aquifer. The results reflect the movement of the plumes as slug sources of chemicals as opposed to continuous sources. The transport of chemicals was also influenced by advection, dispersion, and retardation factors only, biodegradation of chemicals was not applied to the model; therefore, taking a more conservative approach.

Figure 24 illustrates the initially modeled benzene plume based on the March 1994 concentrations. Figures 25 through 27 show the predicted concentrations of benzene after 1, 5, and 10 years assuming no ongoing source of benzene. The highest concentration portion of the initial benzene plume (March 1994) is located at MW-12 with a concentration of 1,800 ppb. After one year the benzene plume has migrated 150 feet downgradient and the maximum concentration has decreased to 1,359 ppb. After 5 years the plume has migrated a total of 600 feet downgradient and the maximum concentration has decreased to 1,348 ppb. After 10 years the plume has migrated a total of 1,500 feet downgradient and the maximum concentration has decreased to 1,194 ppb.

Figure 28 illustrates the initially modeled TCE plume based on the March 1994 concentrations. Figures 29 through 31 show the predicted concentrations of TCE after 1, 5, and 10 years assuming no ongoing source of TCE. The highest concentration portion of the initial TCE plume (March 1994) is located at MW-5 with a concentration of 300 ppb. After one year the TCE plume has migrated 900 feet downgradient and the maximum concentration has decreased to 261 ppb. After 5 years the plume has migrated a total of 3,600 feet downgradient and the maximum concentration has decreased to 203 ppb. After 10 years the highest concentration portion of the plume has migrated beyond the boundaries of the model grid. The highest concentration present in the grid area after 10 years is 64 ppb of TCE present from the secondary plume originally centered at MW-21. After 10 years this secondary plume has migrated 1,700 feet downgradient.

The predicted rates at which the benzene and TCE plumes migrate are consistent with the calculated groundwater velocities and retardation values determined for the site. The faster rate of migration for the primary TCE plume is the result of a higher horizontal hydraulic conductivity present in the western half of the OFRP.

7.3.3 Source Simulation Results

Benzene and TCE plumes were simulated at areas upgradient from the existing benzene and TCE plumes to simulate possible source locations and initial concentrations that would develop into the existing plumes over time. Three different scenarios were modeled and are shown on Figures 32, 33 and 34. One possible source for the existing benzene plume is a former operation that stored benzene in above ground tanks in Area E. An initial benzene plume with a maximum concentration of 5,000 ppb was simulated in Area E (**Figure 32A**). This downgradient migration of this simulated plume was modeled for a period of 10 years. After a period of 5 years the plume had migrated to the location where the benzene plume was present per the March 1994 sample results. The above ground tanks in Area E had been present from the 1940s to 1992. The 5 year time period modeled in this scenario is a relatively short time period given the length of time the tanks were present in Area E. This scenario may reflect more of a gradual input of benzene into groundwater and time for the benzene to migrate down to groundwater. This scenario may also reflect that the benzene source could be further upgradient and has traveled for more than 5 years.

Another initial benzene plume was modeled further upgradient and outside the boundaries of the OFRP. The premise of this scenario was, at what location and initial benzene concentration in groundwater would produce a benzene plume similar to the plume delineated from the March 1994 (**Figure 24**) sample results after a migration period of 10 years. Several model runs were completed until this objective was reached. **Figure 33A** shows the initial benzene plume that would produce a resultant plume after 10 years that is most similar to the benzene plume delineated from the March 1994 sample results. The resultant plume is shown on **Figure 33B**.

An initial TCE plume was modeled further upgradient and outside the boundaries of the OFRP. The objective of this scenario was the same as the one described for initial off-site

simulated benzene plume, which was to determine at what location and initial TCE concentration in groundwater would produce a TCE plume similar to the plume delineated from the March 1994 (**Figure 28**) sample results after a migration period of 10 years. Several model runs were completed until this objective was reached. **Figure 34A** shows the initial TCE plume that would produce a resultant plume after 10 years that's most similar to the TCE plume delineated from the March 1994 sample results. The resultant plume is shown on **Figure 34B**.

These model results indicate a general trend of migration path and rate, and possible initial concentration that would develop into the chemical concentrations measured in the OFRP wells during the March 1994 sampling event. As a result of the distribution of benzene and TCE concentrations measured in the OFRP wells during the three sampling events conducted during this investigation, and the inability to determine the upgradient and downgradient extent of these chemicals, it is not possible to pinpoint specific sources of these chemicals.

8.0 CONCLUSIONS

A groundwater characterization investigation of the OFRP was conducted to assess the current groundwater conditions, determine if any chemicals are present in groundwater above regulatory limits and guidelines, and to determine possible sources of chemicals present in groundwater. To characterize the groundwater conditions beneath the OFRP, 27 groundwater monitor wells were installed, 3 groundwater sampling events were conducted over a 1 year period, (March 1994 through April 1995) and one additional sampling event of three selected wells in April 1996, aquifer testing was conducted, and a groundwater flow and solute transport model was developed for the OFRP and surrounding area.

Based on the data collected during the groundwater characterization study the first groundwater was encountered at an approximate average depth of 62 feet, ranging from 50.6 to 76.9 feet (April 1996). The groundwater is in an unconfined aquifer consisting of Exposition and Gage Aquifers which appear to be interfingering beneath the OFRP. Groundwater flow direction is to the southwest with an average gradient of 0.008 (42 ft/mile). VOCs were detected in all 27 groundwater monitor wells during at least one of the sampling events. Benzene, TCE, and PCE were the most prevalent and highest concentration VOCs detected in groundwater. SVOCs and arsenic were detected in several wells at concentrations above regulatory limits. TPH was also detected in groundwater.

The distribution of these compounds provides some indication of potential source areas and an initial view of the impact of contamination in the regional groundwater on the OFRP. To assist with evaluation of future development of the OFRP areas, the distribution of chemicals in groundwater is discussed below for each OFRP Area.

AREA A

- ▶ HVOCs primarily consisting of TCE, PCE and 1,1-DCE were detected at elevated concentrations (exceeding the MCL) within the western half of Area A.
- ▶ Elevated concentrations of TCE, PCE, and 1,1-DCE were detected in the Area A upgradient well MW-25 at concentrations similar to those detected in the Area A downgradient well MW-30. These concentrations of HVOCs appear to originate from an off-site upgradient source or sources. This conclusion is supported by the solute transport model and the absence of known use of TCE, PCE, and 1,1-DCE from former operations in the western half of Area A. Also, a soil investigation conducted by Environmental Science & Engineering (ESE) in 1993 conducted in the western half of Area A indicated that HVOCs were not detected in soil samples analyzed for HVOCs.
- ▶ TPH was not detected in Area A. Benzene was detected at low concentrations in two wells during the initial sampling event (March 1994) but was not detected in the subsequent 2 sampling events.
- ▶ Based on data from Area B and Area C wells MW-12 and MW-13 located adjacent to Area A it appears that TPH and benzene are present in groundwater beneath the southeast portion of Area A. The data suggest that these chemicals did not originate from Area A.
- ▶ Elevated concentrations of arsenic were detected in well MW-23 in the eastern portion of Area A during the initial sampling event (March 1994). Arsenic was detected in only one well (MW-30) at a trace concentration during the April 1995 sampling event.
- ▶ Based on data from Area B and Area C wells located adjacent to Area A it appears that arsenic is present in groundwater beneath the southeast portion of Area A. The data suggest that arsenic did not originate from Area A. There is no known source of arsenic in Area A.

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- ▶ Based on the results discussed above, chemicals found in groundwater beneath Area A have not originated within Area A.

AREA B

- ▶ HVOCs, primarily TCE, PCE, and 1,1-DCE, were detected at concentrations greater than the MCLs within the western half of Area B.
- ▶ The distribution of these compounds indicate both off-site upgradient chemical source or sources and possible contributions within Area B. Area B consists of 216 lots which are owned by 114 separate owners. Limited information is available on activities conducted on these lots other than former oil field operations. A soil investigation conducted by McLaren/Hart (Town Lots Environmental Assessment, December 1994) revealed that HVOCs were not detected in soil within former oil tank and sump areas and at locations statistically selected outside of the tank and sump areas. Due to restricted access, not all areas were available for investigation. Based on this information, HVOCs detected in groundwater beneath the western portion of Area B, that may partially be the result of activities in Area B do not appear to be the result of former oil field activities.
- ▶ Elevated concentrations of benzene (exceeding the MCL) were consistently detected in monitor wells MW-12, MW-10, and MW-9 located in the eastern portion of Area B. Concentrations of toluene, ethylbenzene, and xylene also exceeding their respective MCLs were found in well MW-12.
- ▶ The distribution of benzene and other BTEX compounds measured in the wells indicate benzene is migrating onto Area B from an upgradient source or sources. The highest concentration of BTEX compounds detected in groundwater beneath Area B were measured in well MW-12 which is the most upgradient well located in Area B (northeast corner of Area B). Sources of BTEX to groundwater have not been documented in Area B by the 1994 McLaren/Hart Area B soil investigation. A prior soil investigation performed by McLaren/Hart in 1992 at the Beaumon Trust Parcel (located North of Park Avenue and east of Forest) did indicate the presence of elevated BTEX concentrations in soil.

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- ▶ TPH (primarily gasoline and diesel range hydrocarbons) was detected in groundwater in the northeast portion of Area B. Based on the distribution of TPH it appears that TPH is migrating onto Area B from an upgradient source or sources. The highest concentration of TPH detected in groundwater beneath Area B was measured in well MW-12 which is the most upgradient well located in Area B (northeast corner of Area B)
 - ▶ Vinyl chloride was detected at concentrations exceeding the MCL in the eastern portion of Area B (MW-9 and MW-10). Vinyl chloride was not detected in monitor well MW-12 which is upgradient of MW-9 and MW-10. However, the detection limits in MW-12 were 200 and 1,000 ppb due to the high concentration of BTEX compounds. Thus if vinyl chloride is present in MW-12, it may not have been seen in the analyses. Vinyl chloride may be originating upgradient from Area B or from former activities conducted in the northeast section of Area B (north of Park Avenue and east of Forest Avenue). Vinyl chloride was detected in soil samples collected from the Beaumon Trust Property located in the northwest section of Area B.
 - ▶ Elevated concentrations of arsenic were detected in 6 of the 11 wells located in Area B during at least one of the two sampling events for metals analysis. There is no known source of arsenic in Area B.
 - ▶ Based on the results discussed above, chemicals found in groundwater beneath Area B have not originated from oil field operations. HVOCs and BTEX compounds may have originated from non-oil field activities west of Springdale Avenue and in the vicinity of Forest and Park Avenues.

AREA C

- ▶ TCE was detected at or slightly above the MCL in the three wells (MW-15, MW-16 and MW-17) during only one of the three sampling events. These wells are located along the upgradient side of Area A. If TCE persists in groundwater it appears to originate from an upgradient off-site source or sources.

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- ▶ Elevated concentrations of benzene (exceeding the MCL) were consistently detected in wells MW-13, MW-15, and MW-17. Concentrations of toluene, ethylbenzene, and xylene also exceeded their respective MCLs in well MW-13. The distribution of benzene and other BTEX compounds measured in the wells indicate benzene is migrating onto Area C and may also be originating from former activities within Area C. The concentration of benzene detected in well MW-17 reflects contribution from an upgradient off-site source since MW-17 is located on the upgradient edge of Area C. The primary source of benzene measured in Area C and extending into Area B appears to be from the former benzene tanks located in Area E.
 - ▶ Elevated concentrations of TPH (primarily diesel and gasoline range hydrocarbons) were detected in groundwater beneath Area C. The highest concentrations were generally detected in wells MW-15, MW-16 and MW-17. The distribution of TPH measured in the wells indicate TPH is migrating onto Area C and may also be originating from former activities within Area C.
 - ▶ A soil investigation conducted by Applied Geosciences, Inc. in Area C indicated that TPH (crude oil and refined hydrocarbons) and BTEX compounds were detected in soil. The vertical extent of these compounds had not been defined at several locations within Area C. An additional soil investigation conducted by McLaren/Hart in June 1996 indicated that TPH and BTEX compounds were present at depth at one boring located in the southwest corner of Area C. The concentration and distribution of BTEX measured at the boring located in the southwest corner of Area C indicates a refined petroleum hydrocarbon source possibly associated with former or current pipelines located in the vicinity of the soil boring. The source of this impact is currently being investigated by the property owner.
 - ▶ Elevated concentrations of phenolic compounds were detected in groundwater in monitor wells MW-15, MW-16, and MW-17 located along eastern boundary of Area C. The sources of these compounds are suspected to be from previous operations conducted in Area E, which is directly east of Area C and/or sources further upgradient. Former operations in Area E included the production and storage of phenolic compounds.

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- ▶ Elevated concentrations of arsenic were detected in all six Area C wells during both sampling events for metals analysis. There is no known source of arsenic in Area C.
 - ▶ Based on the results discussed above, HVOC, phenolic compounds and arsenic found in groundwater beneath Area C have not originated from activities in Area C. Activities in the southwest corner of Area C may have contributed BTEX and TPH to groundwater.

Area D

- ▶ One well (MW-21) was installed at the southwest corner (downgradient corner) of Area D. Results from this well indicate that concentrations of benzene, TCE, PCE, and 1,1-DCE have been detected slightly above their MCLs during at least one of the three sampling rounds. During the most recent sampling event, the only compound detected in MW-11 was TPH at 1.1 ppm.
- ▶ Arsenic was not detected in well MW-21. Based on the concentration of arsenic in wells located in Areas B and C adjacent to Area D it appears that arsenic is present in groundwater beneath the northwest portion of Area D. There is no known source of arsenic in Area D.
- ▶ A portion of the northern section of Area D was remediated as a result of TPH impacted soil. Investigations have not been conducted on the remaining portions of Area D. Based on the results from MW-11 former operations in Area D do not appear to have impacted groundwater and the compounds detected in MW-11 reflect off-site contributions.

AREA E

- ▶ Two groundwater monitoring wells (MW-19 and MW-20) were installed along the upgradient boundary of Area E. Results from these wells indicate concentrations of benzene, TCE, PCE, and 1,1-DCE slightly above their respective MCLs. Based on these results, low concentrations of these compounds appear to be migrating beneath Area E from upgradient off-site sources.

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- ▶ Four groundwater monitor wells were constructed and one grab sample (KB-1) of groundwater was collected in Area E (west of Old Romandel Avenue) during studies unrelated to the OFRP (Figure 35). The grab sample collected during a 1988 site investigation contained 32,000 ppb benzene. KB-1 was located adjacent to a benzene storage tank. Well MW-3 did not contain detectable concentrations of benzene. Wells MW-1, MW-2 and MW-2S were not analyzed for benzene or other VOCs. There are no OFRP wells directly upgradient from the former benzene tanks in Area E to assess if there is contribution from any other upgradient sources.
 - ▶ Phenolic compounds detected in Area C wells are suspected to be from previous operations conducted in Area E (west of Old Romandel Avenue). Former operations in Area E (west of Old Romandel Avenue) included the production and storage of phenolic compounds.

AREA F

- ▶ One well (MW-21) was installed at the upgradient corner (northeast corner) of Area F. Groundwater sample results obtained from this well indicated concentrations of TCE, PCE, and 1,1-DCE above their respective MCLs. Based on the location of MW-21 these concentrations of TCE and PCE appear to be migrating beneath Area F from an upgradient off-site source or sources.
- ▶ High levels of soil vapors were encountered during an initial attempt to install a well in the southern portion of Area F. A well (MW-22) was successfully installed adjacent to the previous location on March 11, 1996. Benzene was detected in MW-22 significantly above the MCL. Based on the groundwater gradient and information obtained from the Ashland Chemical Site located east of Area F, it appears that this benzene concentration is attributed to the Ashland Chemical Site. This conclusion is consistent with previous concurrence with the Los Angeles Regional Water Quality Control Board (letter dated July 12, 1991) regarding previous groundwater results obtained from wells MCC-2 and MCC-4 (**Figure 6D**), located adjacent to Area F, in which VOCs concentrations measured in these wells was attributed to upgradient source(s) specifically Ashland Chemical Company.

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- ▶ Barium was detected in MW-22 at a concentration above its MCL. The barium appears to be originating from an upgradient source or sources from Area F. There is no known source of barium in Area F.

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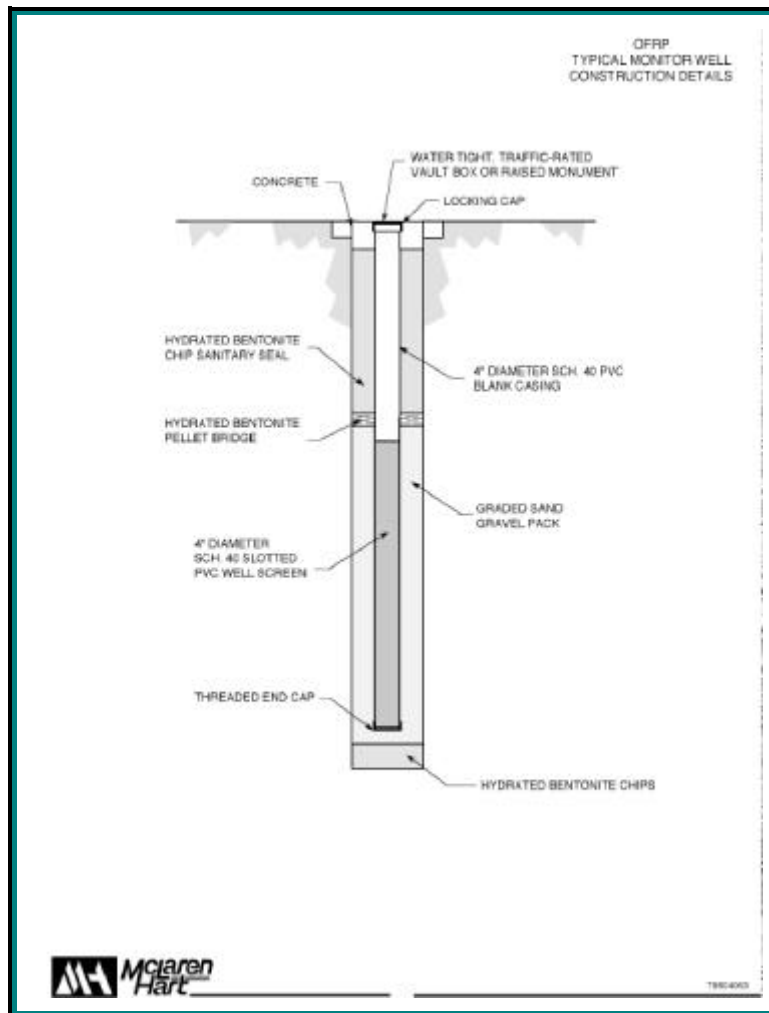
Appendix A

McLaren/Hart Standard Field Protocols

WELL INSTALLATION PROTOCOLS

All groundwater monitor wells were constructed with flush threaded, 4-inch-outside-diameter (O.D.), Schedule 40 PVC blank casing and 4-inch-O.D., machine-slotted PVC screen. The screened interval extends approximately 3 to 5 feet above the static water level. The annular space between each well screen and borehole were packed with a clean, graded sand, which extends from the bottom of the borehole to 2 feet above the screened interval.

A 2- to 3-foot bentonite pellet seal was placed above the sand pack followed by a hydrated bentonite chip sanitary seal to approximately 3 feet below grade. Concrete was placed to ground surface, and both a locking cap and traffic-rated, watertight vault box were installed.



WELL DEVELOPMENT PROTOCOLS

Monitor wells were developed with a SMEAL 5-T Development Rig using standard surging and bailing techniques prior to groundwater sampling. Each monitor well was surged using an appropriately sized surge block attached to a 3-foot section of steel weight and a steel cable line. The wells were surged in approximately 3-foot intervals, which forced groundwater to flow into and out of the well screen and allowed the filter pack to settle effectively and fine-grained sediments to break up, go into suspension, and then migrate into the well. The wells were then bailed with a clean stainless steel bailer to remove a portion of the silts and clays. The wells were further developed by having a minimum of 10 casing volumes of groundwater removed by pumping or bailing. This reduced the turbidity of the water-bearing zone and allowed representative aquifer water to enter the well. During development, water pH, conductivity, and temperature were monitored.

The bailer and submersible pump were washed thoroughly with detergent solution and rinsed with both tap water and deionized water before each well was developed. The groundwater removed during development was stored on-site in 55-gallon DOT-approved drums and later transferred to a holding tank for profiling and disposal.

The location and vertical elevation of each well were surveyed relative to an on-site datum or nearby bench mark. The wells were surveyed by a licensed surveyor using an automatic level mounted on a tripod, and a measuring rod.

The groundwater surface elevations of all wells were measured with an electronic oil/water interface sounder.

SAMPLING PROTOCOLS

Groundwater samples were collected from each well using the appropriate glassware/containers for the analytes that were to be run. All samples were obtained at least 72 hours after the wells had been developed. Groundwater samples were collected with a disposable polyethylene bailer with stopcock, which was lowered down the well via nylon cord. All equipment (including the nylon cord) were disposed of between sampling events.

A sample blank and trip blank were also obtained for analysis. The sample blank is a vial of distilled water that is circulated through the bailer prior to sampling. The trip blank is a vial of distilled water included in the thermally-insulated ice chest during sampling and shipping. These blanks are used to provide an indication of contamination introduced as a consequence of the sampling and shipping procedure. All groundwater samples were labeled, sealed, stored in airtight plastic bags, placed in a thermally insulated chest with ice, and delivered under chain-of-custody to a State-certified hazardous waste testing laboratory.

SLUG TEST PROTOCOLS

Slug tests were conducted in groundwater monitor wells MW-1 thru MW-21, MW-23, and MW-24 to obtain representative hydraulic conductivity and transmissivity values in the first occurring aquifer surrounding the wells at the site. A slug test consists of two subtests called “slug-in” and “slug-out” tests. During a slug-in test, water level in the well is raised by introducing a slug into the well beneath the water level. This action causes the water level in the well to increase above the surrounding water level in the aquifer. A slug-out test has the opposite effect. The slug is pulled from the well and the water level in the well decreases below the water level in the aquifer. The slug tests records the rate at which the water level in the well reestablishes equilibrium with the water level in the aquifer after the slug is introduced or removed from the well. The rate at which equilibrium is achieved is a function of the aquifers hydraulic conductivity and transmissivity. A Hermit model 2000 four-channel datalogger was used to monitor and record the rate of water level change during the slug tests. A 3.5-inch O.D., non-buoyant cylinder (approximately 3 feet long) was used for the slug.

Before starting a slug test, aquifer test parameters were entered into the datalogger. A pressure transducer was attached to the datalogger and lowered to the bottom of the well. The water level in the well was initially measured using an electric water sounder. A nylon rope was attached to the top of the slug and the distance from the top of casing to the static water level in the well was measured marked on the rope. Two additional feet were measured and the rope was marked again. The rope was attached to a pulley on a tripod. The slug was lowered into the well to 1 foot above the water level. The rope was released quickly and the slug was submerged until the top of the slug was approximately two feet below the top of water (slug-in test). The datalogger was immediately activated and the rate of equilibration of the water level to the aquifer water level was recorded for the duration of the test.

The second part of the slug test (slug-out test) measured the rate of equilibration of the water level to the aquifer water level when the slug was removed from the well. The datalogger was reactivated immediately after the slug was pulled from the water and the equilibration rate was recorded for the duration of the test.

PUMPING TEST PROTOCOLS

A pumping test was also conducted to obtain values of hydraulic conductivity and transmissivity in the first occurring aquifer in the vicinity of monitor wells MW-10. A pumping test involves pumping one well at a constant rate and measuring the rate of draw-down in the well. The rate of drawdown is also measured in adjacent wells.

A preliminary pumping test was conducted in MW-10 to determine an appropriate drawdown rate. The transducer was placed 2 feet from the bottom of the well. A SMEAL development rig was used to lower a 4 inch submersible pump to a depth of 4.5 feet from the bottom of pumping well MW-10. The pump was engaged and water was withdrawn at rates ranging from approximately 6.5 to 8 gallons per minute (gpm). Based on the drawdown rates observed during the preliminary pump test, a pumping rate of 5.5 gpm was to be used for the pumping test. The pump was disengaged and the well allowed to recover to static level.

The next day the pumping test was conducted using monitor wells AMW-1, AMW-2, and AMW-3 as observation wells and well MW-10 as the pumping well. Groundwater monitor well AMW-1 is located 136.30 feet from pumping well MW-10; AMW-2 is located 24.25 feet from pumping well MW-10; AMW-3 is located 24.20 feet from pumping well MW-10. A pressure transducer was lowered into each well. The pressure transducers were connected to the datalogger to record the drawdown rate in MW-10 and the potential drawdown rate in the observation wells. Electric water sounders were used to monitor potential drawdown rates in MW-9, and MW-12. The water level in both the pumping well and the observation wells were monitored and recorded for the duration of the test. The pump test was started using a pumping rate of 5.5 gpm. After 731 minutes the well was pumped “dry” and the pump was turned off. After the pump was turned off, the recovery was recorded, in the same manner as the pumping phase of the test.



Appendix B

Soil Boring/Well Construction Logs

Soil Boring/ Well Construction Logs

MW-1	MW-15
MW-2	MW-16
MW-3	MW-17
MW-4	MW-18
MW-5	MW-19
MW-6	MW-20
MW-7	MW-21
MW-8	MW-22
MW-9	MW-23
MW-10	MW-24
MW-11	MW-25
MW-12	MW-29
MW-13	MW-30
MW-14	

Appendix C

Laboratory Analytical Data Sheets: Soil

NOTE: Not included on this CD-ROM due to the size and format of the information. The analytical results have been summarized in the **Tables** section of this report.

Appendix D

Laboratory Analytical Data Sheets: Physical Parameters Soil

NOTE: Not included on this CD-ROM due to the size and format of the information. The analytical results have been summarized in the **Tables** section of this report.

Appendix E

Laboratory Analytical Data Sheets: Groundwater

- **March 1994**
- **October 1994**
- **April 1995**
- **April 1996**

NOTE: Not included on this CD-ROM due to the size and format of the information. The analytical results have been summarized in the **Tables** section of this report.

Appendix F

Slug and Pumping Test AQTESOLV Plots

Slug and Pumping Test AQTESOLV Plots

SMW-01

SMW-02

SMW-03

SMW-04

SMW-05

SMW-06

SMW-07

SMW-08

SMW-09

SMW-10

SMW-11

SMW-12

SMW-13

SMW-14

SMW-15

SMW-16

SMW-17

SMW-18

SMW-19

SMW-20

SMW-21

SMW-23

SMW-24

Pump Test Results

Appendix G

MODFLOW Output Files

Appendix H

MT3D Output Files

- **Downgradient Transport of Benzene,**
10 Year Simulation
- **Downgradient Transport of TCE,**
10 Year Simulation
- **Suspected Benzene Source Transport Simulation,**
5 Year Simulation
- **Potential Benzene Source Transport Simulation,**
10 Year Simulation
- **Potential TCE Source Transport Simulation,**
10 Year Simulation